UPDATED FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND U.S. LANDFALL STRIKE PROBABILITIES FOR 2002

A below average Atlantic basin hurricane season is now envisioned for 2002. This update extends the steady downward series of adjustments from our earlier 2002 seasonal forecasts in response to global conditions which have steadily become less favorable for Atlantic hurricane activity.

This forecast is based on ongoing research by the authors utilizing meteorological information as available through July 2002

By
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[Both this and prior forecasts are available at the following World Wide Web address: http://tropical.atmos.colostate.edu/forecasts/index.html — you also may contact:

Brad Bohlander and Thomas Milligan, Colorado State University media representatives who are available to respond to inquiries regarding this forecast (970-491-6432).

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2002 ATLANTIC BASIN SEASONAL HURRICANE FORECAST

Tropical Cyclone Parameters and 1950-2000 Climatology (in parentheses)	7 December 2001 Forecast for 2002	Updated 5 April 2002 Forecast	Updated 31 May 2002 Forecast	Updated 7 Aug 2002 Forecast
Named Storms (NS) (9.6)	13	12	11	9
Named Storm Days (NSD) (49.1)	70	65	55	35
Hurricanes (H)(5.9)	8	7	6	4
Hurricane Days (HD)(24.5)	35	30	25	12
Intense Hurricanes (IH) (2.3)	4	3	2	1
Intense Hurricane Days (IHD)(5.0)	7	6	5	2
Hurricane Destruction Potential (HDP) (72.7)	90	85	75	35
Net Tropical Cyclone Activity (NTC)(100%)	140	125	100	60

PROBABILITIES FOR LANDFALL OF AT LEAST ONE OR MORE MAJOR (CATEGORY 3-4-5) HURRICANE ON EACH OF THE FOLLOWING COASTAL AREAS:

1) Entire U.S. coastline – 49% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida – 28% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville – 29% (average for last century is 30%)

4) Major hurricane landfall risk in the Caribbean during 2002 is below average.

HOW CSU SEASONAL HURRICANE FORECASTS ARE DIFFERENT THAN THE FORECASTS RECENTLY BEING ISSUED BY NOAA

Colorado State University (CSU) has issued seasonal hurricane forecasts for the last 19 years. The forecasts, which are issued in December of the prior year, and in April, June, and August of the current year, have steadily improved through continuing research. CSU forecasts now include individual monthly predictions of Atlantic basin activity and seasonal and monthly U.S. hurricane landfall probabilities.

The National Oceanographic and Atmospheric Administration (NOAA) has also begun to issue Atlantic basin seasonal hurricane forecasts. These NOAA forecasts are independent of the CSU forecasts although they utilize prior CSU research which they augment via their own insights. One should not expect that the NOAA and the CSU forecasts to necessarily be in agreement. Chris Landsea and Eric Blake, former CSU project members presently employed by NOAA, are making important contributions to both forecasts.

SEPTEMBER-ONLY FORECAST AND SEASONAL UPDATE

Starting this year on Monday September 2, 2002 (Labor Day), we will for the first time be issuing a revised September-only forecast as well as a revised seasonal outlook which will utilize data through August. This September-only forecast and seasonal update will be transmitted onto our CSU forecast Web site:

[http://tropical.atmos.colostate.edu/forecasts/index.html]

DEFINITIONS

Atlantic Basin - The area including the entire North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico.

El Niño - (EN) A 12-18 month period during which anomalously warm sea surface temperatures occur in the eastern half of the equatorial Pacific. Moderate or strong El Niño events occur irregularly, about once every 3-7 years or so on average.

Hurricane - (H) A tropical cyclone with sustained low level winds of 74 miles per hour (33 ms^{-1} or 64 knots) or greater.

Hurricane Day - (HD) A measure of hurricane activity, one unit of which occurs as four 6-hour periods during which a tropical cyclone is observed or estimated to have hurricane intensity winds.

Hurricane Destruction Potential - (HDP) A measure of a hurricane's potential for wind and storm surge destruction defined as the sum of the square of a hurricane's maximum wind speed (in 10^4 knots^2) for each 6-hour period of its existence.

Intense Hurricane - (IH) A hurricane which reaches a sustained low level wind of at least 111 mph (96 kt or 50 ms^{-1}) at some point in its lifetime. This constitutes a category 3 or higher on the Saffir/Simpson scale (also termed a "major" hurricane).

Intense Hurricane Day - (IHD) Four 6-hour periods during which a hurricane has intensity of Saffir/Simpson category 3 or higher.

MATL - Sea surface temperature anomaly in the sub-tropical Atlantic between 30-50°N, 10-30°W

MPD - Maximum Potential Destruction - A measure of the net maximum destruction potential during the season compiled as the sum of the square of the maximum wind observed (in knots) for each named storm. Values expressed in 10^3 kt.

Named Storm - (NS) A hurricane or a tropical storm.

Named Storm Day - (NSD) As in HD but for four 6-hour periods during which a tropical cyclone is observed (or is estimated) to have attained tropical storm intensity winds.

NATL - Sea surface temperature anomaly in the Atlantic between 50-60°N, 10-50°W

NTC - Net Tropical Cyclone Activity - Average seasonal percentage mean of NS, NSD, H, HD, IH, IHD. Gives overall indication of Atlantic basin seasonal hurricane activity (see Appendix B).

ONR - previous year October-November SLPA of subtropical Ridge in eastern Atlantic between 20-30°W.

QBO - Quasi-Biennial Oscillation - A stratospheric (16 to 35 km altitude) oscillation of equatorial east-west winds which vary with a period of about 26 to 30 months or roughly 2 years; typically blowing for 12-16 months from the east, then reverse and blowing 12-16 months from the west, then back to easterly again.

Saffir/Simpson (S-S) Category - A measurement scale ranging from 1 to 5 of hurricane wind and ocean surge intensity. One is a weak hurricane whereas 5 is the most intense hurricane.

SLPA - Sea Level Pressure Anomaly - The deviation of Caribbean and Gulf of Mexico sea level pressure from observed long term average conditions.

SOI - Southern Oscillation Index - A normalized measure of the surface pressure difference between Tahiti and Darwin.

SST(s) - Sea Surface Temperature(s).

SSTA(s) - Sea Surface Temperature(s) Anomalies.

Tropical Cyclone - (TC) A large-scale circular flow occurring within the tropics and subtropics which has its strongest winds at low levels; including hurricanes, tropical storms, and other weaker rotating vortices.

Tropical Storm - (TS) A tropical cyclone with maximum sustained winds between 39 (18 ms^{-1} or 34 knots) and 73 (32 ms^{-1} or 63 knots) miles per hour.

TATL - Sea surface temperature anomaly in the Atlantic between 8-22°N, 10-50°W.

ZWA - Zonal Wind Anomaly - A measure of upper level ($\sim$ 200 mb) west to east wind strength. Positive anomaly values mean winds are stronger from the west or weaker from the east than normal.

1 knot = 1.15 miles per hour = 0.515 meters per second.

ABSTRACT

Information obtained through early August 2002 indicates that the 2002 Atlantic basin seasonal hurricane activity will be below the average for the 1950-2000 period. The more active season anticipated in our earlier 7 December 2001, 5 April 2002, and 31 May 2002 updated forecasts has been revised downward. Predictive signals from around the globe have trended sharply towards inhibiting conditions during the last four months. These conditions now indicate significantly less tropical cyclone activity than earlier expected. Strong cyclone suppressing influences now expected to be present and likely to persist in the tropical Atlantic include below normal Sea Surface Temperatures (SST), above normal Sea Level Pressure (SLP), above average easterly trade winds, and stronger than average upper tropospheric westerly winds. In association with these factors, the weak El Niño event we expected in our earlier forecasts is now a moderate event which is also a suppressing influences. We now anticipate that 2002 will have 9 named storms (average is 9.6), 35 named storm days (average is 49.1), 4 hurricanes (average is 5.9), 12 hurricane days (average is 24.5), 1 intense (category 3-4-5) hurricane (average is 2.3), 2 intense hurricane days (average is 5.0), Hurricane Destruction Potential (HDP) of 35 (average is 72.7) and overall Net Tropical Cyclone (NTC) activity of 60 percent of the long-term seasonal average for 1950-2000. United States landfall probability for 2002 is now estimated to be below the long-term average, but is less diminished than the ancitipated overall Atlantic basin activity.

1 Introduction

Our evolving forecast techniques are based on a variety of global and regional predictors previously shown to be related to forthcoming seasonal Atlantic basin tropical cyclone activity and U.S. landfall probability. This report presents details of our most recent observations as well as the rationale for our extended range forecast of the 2002 Atlantic hurricane season. These forecasts are based on both statistical and analog analyses of prior hurricane seasons which had atmospheric and oceanic conditions similar to what we anticipate to be in place during the 2002 hurricane season. Summaries of our three most recent seasonal hurricane activity forecasts and end of season verifications are presented in the Appendix. Earlier Web reports have verification data back to 1984.

Our research has shown that a sizable portion of the season-to-season variability of Atlantic tropical cyclone activity can be forecast with skill exceeding that of the climatological average by early December of the prior year with increasing forecast skill by early April, late May and early August. Qualitative forecast adjustments are added to accommodate additional processes which are not incorporated into our statistical and analog models. As in most seasons, the two most prominent influences which will largely determine the trend in this year's Atlantic hurricane activity are:

(1) The status of El Niño-Southern Oscillation (ENSO). A moderate intensity El Niño is currently in place in the eastern equatorial Pacific and should be an inhibiting influence on the 2002 hurricane activity.

(2) The configuration of Atlantic Sea Surface Temperature Anomaly (SSTA) conditions. Tropical Atlantic SSTA conditions have cooled significantly during the last few months and are now

below average. This condition should be an inhibiting influence for this years hurricane activity.

(3) The June-July Sea Level Pressure Anomalies (SLPA) in the Caribbean and tropical Atlantic. Surface pressure are substantially above average and should be a strong inhibiting influence for this years hurricane activity.

(4) The phase of the stratospheric Quasi-Biennial Oscillation (QBO) of zonal winds at 30 and 50 mb (which can be accurately extrapolated into the future). This season's QBO winds will be from a TC enhancing westerly mode. This is the only enhancing physical parameter that we can detect.

(5) Two measures of West African rainfall during the prior year (Figs. 1 and 2) which, when above average, indicate increased hurricane activity. Our estimates of rainfall in the Gulf of Guinea during August through November 2001 was 1.25 SD below average. Similarly, our estimate of June-July 2002 rainfall in the western Sahel is 1.25 SD below average. These rainfall estimates indicate below average hurricane activity for this season.

(6) Zonal Wind Anomalies (ZWA) at 200 mb in the Caribbean basin (Trinidad, Curacao, Barbados, Kingston and Balboa) and in the tropical Atlantic are anomalously strong from the west and should also be a significant inhibiting influence for 2002 hurricane activity.

(7) Strength of the low level (approximately 850 mb) trade winds in the tropical Atlantic (ZWA-T). These easterly winds are currently stronger than average and are likely to remain so for the duration of the season and constitute yet another inhibiting influence on this year's Atlantic hurricane activity. Thus, six of the seven important components for 2002 hurricane activity indicates a below average season.

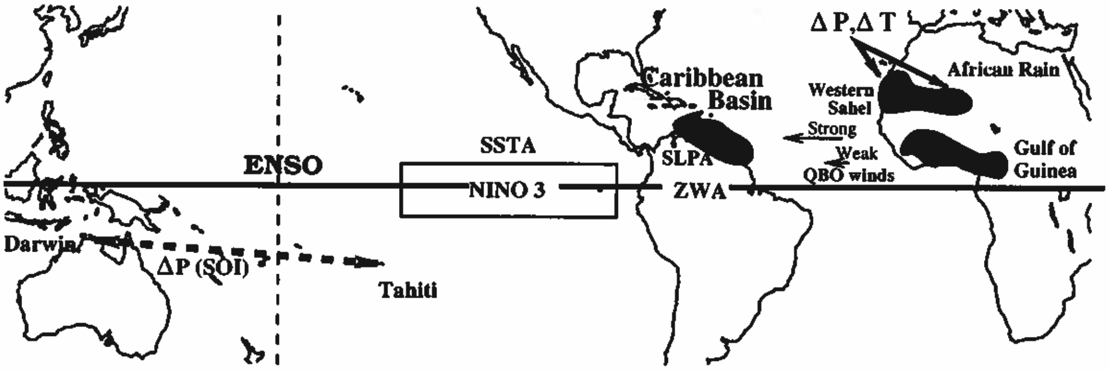

Figure 1: Meteorological parameters used in various versions of our older early August (Gray et al. 1994a) seasonal forecast.

Figures 1-3 show the global locations of our seasonal forecast parameters for our early December, early April, early June and early August forecasts. As we approach the beginning of the active (August-October) part of the hurricane season, conditions in the Atlantic become more dominant predictors.

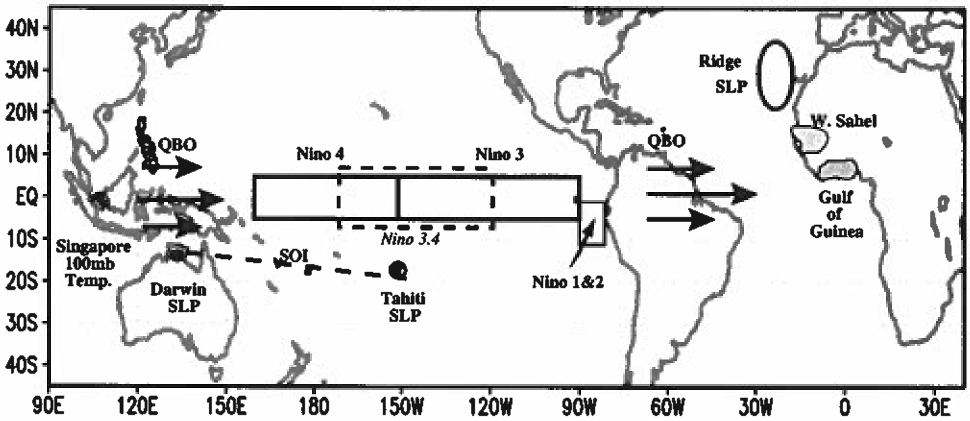

Figure 2: Additional parameters used or consulted in our extended-range forecasts.

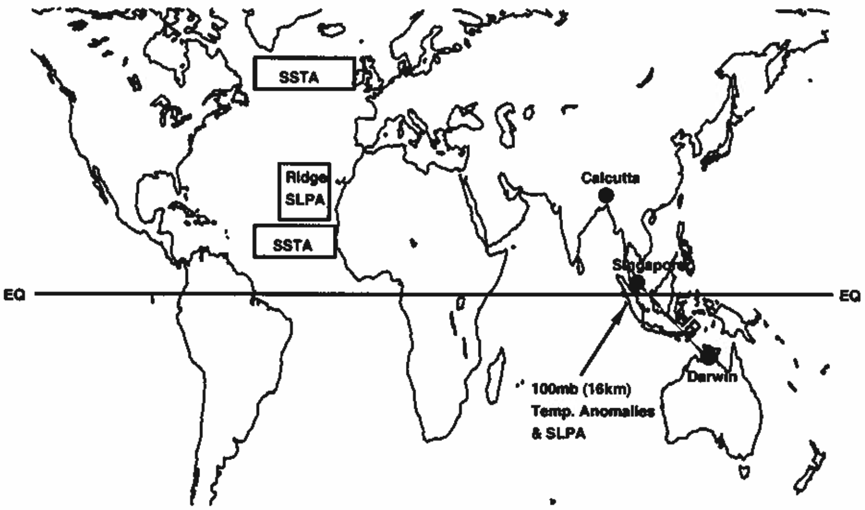

Figure 3: Additional (new) predictors which have recently been noted to be related to the upcoming Atlantic hurricane activity.

2 Recent Advancements in the Potential for Improved Empirical Climate Prediction

The last few years have seen tremendous growth in the accessibility of global atmospheric data sets. An example of this improved accessibility is the NOAA/NCEP global reanalyses which archive and analyze historical atmospheric and ocean surface data and make these data easily available on the Internet. Other countries and international groups are also developing similar reanalysis programs. Most of these reanalysis data sets are available from the late 1940s to the present and offer exciting opportunities for the development of new and improved extended range empirical climate forecast schemes. Broad-scale circulation features identifiable in the reanalysis data fields have considerable precursor information for predicting forthcoming monthly and seasonal hurricane activity.

3 Prediction Methodology

We forecast nine measures of seasonal Atlantic basin tropical cyclone activity including seasonal values for the following: Named Storms (NS), Named Storm Days (NSD), Hurricanes (H), Hurricane Days (HD), Intense Hurricanes (IH), Intense Hurricane Days (IHD), Hurricane Destruction Potential (HDP), Net Tropical Cyclone Activity (NTC), and Maximum Potential Destruction (MPD). Definitions for these indices are given on page 4. For each of these measures of activity, we choose the best three to six predictors (i.e., those resulting in optimum prediction skill) from a group of 15 potential forecast parameters known to be related to tropical cyclone activity. The current set of potential predictors used to develop our early August forecast is shown in Table 1. The specific values of these parameters used for 2002 are shown in the right–hand column.

Statistical Regression Models. A number of statistical forecasts are made for each of several TC activity parameters. Table 2 lists the seasonal hurricane indices that we predict and the number and name of the forecast parameters we use for each forecast. Our hindcast skill (between 50-60 percent) for the 42-year period of 1950–1991 is shown in the right column. These prediction equations are established for our variable parameter forecast model. This represents our best statistical forecast where, so as to minimize the skill degradation of these equations when making independent forecasts via statistical "overfitting", we include the least number of predictors for the greatest amount of hindcast variance. We stop adding predictors when the hindcast improvement for the next best predictor adds less than a 2.5 percent improvement to the total variance explained. These equations are also constrained to have regression coefficients whose sign match those when analyzed in isolation.

We have also studied a scheme which uses various fixed (maximum) numbers of the predictors listed in Table 1. This procedure considers how hindcast variance (not necessarily true skill) increases as the number of predictors increases from 4 to 6 to 8. Although independent forecast skill (i.e., "true skill") typically degrades in approximate proportion to the increased number of predictors, it is of interest to assess the degree of hindcast improvement which occurs with added predictors. Individual year forecast skill degradation from application of hindcast statistics can never be accurately specified. Consequently, as the latter are purely random effects, the hazards of

Table 1: Listing of the pool of predictive parameters and their estimated values for the early August 2002 prediction, based on meteorological data available through July 2002. See Figs. 2 through 4 for the locations of the sources of these predictor data.

Predictive Parameter	
1 = QBO 50 mb 2-month extrapolation of zonal wind at 12°N to Sept. 2002	0 ms^{-1}
2 = QBO 30 mb 2-month extrapolation of zonal wind at 14°N to Sept. 2002	–4 ms^{-1}
3 = QBO absolute value of shear between 50 and 30 mb at 8°N extrapolated to Sept. 2002	4 ms^{-1}
4 = Rgc AN Gulf of Guinea rainfall anomaly (Aug-Nov of 2001)	–1.25 SD
5 = Rws West Sahel rainfall anomaly (June-July 2002)	–1.25 SD
6 = SST3.4 Nino 3.4 SSTA in June-July 2002	+0.9°C
7 = ZWA June-July 2002 Caribbean basin zonal wind anomaly	+1.2 m/s
8 = SLPA June-July 2002 Caribbean basin sea level pressure anomaly	+1.0 mb
9 = Temp West-East Sahel temperature gradient(Feb-May 2002)	+0.1 SD
10 = NATL North Atlantic SSTA anomaly (50-60°N,10-50°W) (June-July)	–0.2°C
11 = SATL South Atlantic SSTA anomaly (5-18°S,50°W-10°E) (June-July)	+0.2°C
12 = TATL Tropical Atlantic SSTA anomaly (10-22°N,18-50°W) (June-July)	–0.3°C
13 = R-M: Mar Azores surface pressure ridge strength in Mar 2002	0.25 SD
14 = R-ON: Azores surface pressure ridge strength in Oct-Nov 2001	+0.15 SD
15 = D-SST3.4: Nino 3.4 SSTA for June-July minus April-May 2002	+0.60°C
16 = NSD-S: Named storm days south of 23.5°N and east of 75°W before 1 August	0

Table 2: Details of our 1 August forecast scheme which utilizes variable selection of predictors so as to maximize forecast skill (hindcast variance explained) while limiting the number of predictors to minimize artificial skill. See Figs. 1-3 for the locations of the predictors. Data for the period 1950–1997 were used to develop these equations.

Forecast Parameter	No. of Predictors	Hindcast Measure of Agreement	Expected Independent Fcst Skill	Predictors
(NS)	5	.602	.463	U_{50}, Shear, R_g, R-ON, NSD-S
(NSD)	3	.518	.363	U_{50}, R_g, NSD-S
(H)	5	.560	.406	U_{30}, R_g, R-M, R-ON, NSD-S
(HD)	4	.513	.341	U_{30}, R_g NATL, NSD-S
(IH)	5	.574	.425	U_{50}, R_s, R_g, D–T, R-M
(IHD)	5	.573	.424	U_{50}, R_g, D–T, R-M, NSD-S
(HDP)	4	.507	.332	U_{30}, R_g, NATL, NSD-S
(NTC)	5	.628	.497	U_{30}, R_g, R-M, R-ON, NSD-S
(MPD)	6	.672	.548	U_{30}, R_g, NATL, R-M, R-ON, NSD-S

overfitting become obvious. Additional forecast parameters representing conditions in the Atlantic and Pacific Ocean basins and in the Asia-Australia regions (refer to Figs. 1-3) are also consulted for further qualitative inter-relations and possible influences on our final "adjusted" forecast.

Probability dictates that, on average, a net degradation of this hindcast skill of between 10-20 percent of total variability will occur. The amount of degradation for an individual year forecast is a random process. In some years, when conditions include strong trends that are similar to past years, forecasts will do quite well, perhaps better than the skill of the hindcast scheme. In other years, a given forecast can perform quite poorly, this owing to our 42-year (1950-1991) predictor database not containing realizations expressing the full range of independent possibilities. Our 1997 forecast is a good example of the latter consideration. No year in our 1950 through 1991 developmental data sets had experienced an El Niño event nearly as intense as 1997 (by a factor of two).

In Table 3, column (1) lists each of our statistical forecast parameters for 2002, column (2) contains our best qualitatively adjusted "final" forecasts and column 3 provides the climatological mean for each parameter for 1950-2000.

Table 3: 1 August season statistical forecasts which have a variable number of predictors (column 1) . Column 2 is our final adjusted early August forecast of 2002 hurricane activity. Column 3 gives climatology.

Full Forecast Parameter	(1) Variable Predictor	(2) Adjusted Actual Fcst	(3) 1950-2000 Climatology
Named Storms (NS)	9.2	9	9.6
Named Storm Days (NSD)	33.8	35	49.1
Hurricanes (H)	5.1	4	5.9
Hurricane Days (HD)	10.4	12	24.6
Intense Hurricanes (IH)	1.2	1	2.3
Intense Hurricane Days (IHD)	1.9	2	5.0
Hurricane Destruction Potential (HDP)	25.5	35	72.7
Net Tropical Cyclone Activity (NTC)	71.3%	60%	100%

Forecast of Post-1 August Activity. Table 4 lists both our original and revised quantitative forecasts for the post-1 August hurricane activity. Our forecast for the remainder of the hurricane season (i.e., August through November) is for below-average tropical storm and hurricane activity.

4 Analog-Based Estimates of Hurricane Activity During 2002

Certain years in the historical record have global oceanic and atmospheric trends which are notably analogous to those we have seen thus far for 2002 and expect to see during the remainder of the 2002 hurricane season. Such analog years provide useful clues as to what the forthcoming 2002 hurricane season may bring. For this (1 August) extended range forecast, we measure June and July atmospheric and oceanic conditions and compare these conditions with June-July conditions

Table 4: Summary of forecasts for the entire 2002 season (column 1) using prior methodology and, for activity after August 1 (columns 2-3) using a new scheme.

Forecast Parameter	(1) New Variable Predictor for Post 1 Aug Activity	(2) After 1 Aug Climatology	(3) Qualitative Adjusted After 1 Aug Activity	Forecast Full Hurricane Season Total for 2002
(NS)	5.9	7.8	8	9
(NSD)	29.7	41.1	34	35
(H)	5.1	5.1	4	4
(HD)	8.4	21.4	12	12
(IH)	1.2	2.0	1	1
(IHD)	1.0	4.4	2	2
(HDP)	34.4	64.4	35	35
(NTC)	69.9	97	59	60

of prior years with high and low hurricane activity. From observations of the global atmosphere and ocean conditions since 1948, we find only three prior years with similarity to June and July 2002 conditions of 1965, 1986, 1994. We also observe a number of similarities with the seasons of 1991, 1992 and 1993.

4.1 Analog Determination for 2002

A series of unusually sharp global atmospheric and oceanic changes have occurred since March of this year. Global changes during the last four months (March through July) indicate a significant changes in our forecast of Atlantic basin hurricane activity for this year. Since March 2002, the Atlantic basin has experienced the following trends: (1) large rises in SLPA, (2) large decreases in SSTA, (3) significant increases in tropical Atlantic upper tropospheric (~ 200 mb) westerly winds (ZWA) across the deep tropics, and (4) significant increases in the easterly tropical Atlantic low level (~ 850 mb) trade winds (ZWA-T).

These Atlantic basin changes all constitute inhibiting features for Atlantic basin seasonal hurricane activity. In addition, the weak El Niño in the eastern tropical Pacific has become somewhat stronger and is likely to negatively influence the Atlantic basin hurricane activity for this season. Hence, when we combine all of these recent month inhibiting factors, we conclude that the coming Atlantic hurricane season is likely to be substantially reduced from the mean of the very active past seven years. This does not mean that hurricane landfall and significant U.S. and Caribbean basin hurricane spawned destruction will not occur, but only that its probability is diminished somewhat over the average hurricane season.

As noted above, in an analysis of all the hurricane seasons back to 1948, we find only a few seasons resembling this year's combination of unfavorable July major circulation and ocean features. The years which are most similar to 2002 are 1965, 1986 and 1994 - very quiet years in terms of Atlantic hurricane activity. Table 5 shows the low amounts of hurricane activity that occurred in these three (since 1948) analog years. Table 6 lists three additional analog years (1991, 1992, and

1993) in which two to three of the above July inhibiting SLPA, SSTA, ZWA and ZWA-T features were in the same inhibiting sense as this year. These were also very inactive seasons.

Table 5: Seasonal hurricane activity in three best analog years for 2002.

Year	NS	NSD	H	HD	IH	IHD	HDP	NTC
1965	6	40	4	27	1	6.25	73	86
1986	6	23	4	10	0	0	25	36
1994	7	28	3	7	0	0	15	34
Mean of 3-yr	6.3	30.3	3.7	14.7	0.3	2.1	37.7	52
2002 Fcst	9	35	4	12	1	2	35	60

Table 6: Three additional though less similar analog years.

Year	NS	NSD	H	HD	IH	IHD	HDP	NTC
1991	8	22	4	8	2	1.25	22	59
1992	6	39	4	16	1	3.25	51	66
1993	8	30	4	10	1	0.75	23	53
Mean of 3-yr	7.3	30.3	4	11.3	1.3	1.75	32	59.3
2002 Fcst	9	35	4	12	1	2	35	60

Table 7 lists our earlier forecasts for the 2002 Atlantic basin hurricane season. Inspection of this table shows the steadily downward adjustment of our forecast as increasingly cyclone inhibiting global atmospheric and oceanic conditions have emerged. Note especially the large decrease in the forecast activity for the 7 August versus the 31 May forecast.

Table 7: Summary of seasonal forecasts for the entire 2002 season and for activity after 1 August.

Tropical Cyclone Parameters and 1950-2000 Climatology (in parentheses)	7 December 2001 Forecast for 2002	Updated 5 April 2002 Forecast	Updated 31 May 2002 Forecast	Updated 7 Aug 2002 Forecast	After 1 Aug 2002 Forecast
NS (9.6)	13	12	11	9	8
NSD (49.1)	70	65	55	35	34
H (5.9)	8	7	6	4	4
HD (24.5)	35	30	25	12	12
IH (2.3)	4	3	2	1	1
IHD (5.0)	7	6	5	2	2
HDP (72.7)	90	85	75	35	35
NTC (100%)	140	125	100	60	59

4.2 Likely Early End of the 2002 Hurricane Season

During El Niño years (as 2002 will be) October and November hurricane activity is typically suppressed. For example, during the strongest El Niño years of the last century, the average number of hurricanes forming in October and November has been only 35-40 percent of the number which developed in non- El Niño seasons. Allowing that 2002 becomes a moderate El Niño year, we then expect that most of this season's hurricane activity will occur before October.

5 Predictions of Individual Monthly Atlantic TC Activity

A new aspect of our climate research is the development of TC activity predictions for individual months. There are often monthly periods within active and inactive Atlantic basin hurricane seasons which do not conform to the overall season. For example, 1961 was an active hurricane season (NTC of 222), but there was no TC activity during August; 1995 had 19 named storms but only one named storm developed during a 30-day period during the peak of the hurricane season, between 29 August and 27 September. By contrast, the inactive season of 1941 had only six named storms (average 9.3), but four of them developed during September. During the inactive 1968 hurricane season, three of the eight named storms formed in June (June average is 0.5). Three named storms also formed during September 1968.

We have started new research to see how well various sub-season or individual monthly trends of TC activity can be forecast. This effort has recently been documented in project reports by Eric Blake (2002) for August and Phil Klotzbach (2002) for September. These reports show how it is possible to develop a skillfully predictive scheme for August-only and September-only Atlantic basin tropical cyclone activity. On average, August, September and October have about 26, 48, and 17% of total NTC, respectively. Initial August-only forecasts have now been made by Blake for 2000 and 2001 and their verification looks promising.

It has been generally thought that it is more difficult to predict hurricane activity during shorter periods than to predict activity for the entire season. Despite the presumed inherent difficulties with these shorter period forecasts, Blake and Klotzbach have devised quite skillful August-only and September-only prediction schemes based on 51 years (1950–2000) of hindcast testing using a statistically independent jackknife approach. Predictors are largely derived from June and July (NCEP global reanalysis) data, but also include information from earlier in the year. See the reports by Blake (2002) and Klotzbach (2002) for more information.

5.1 Independent August-Only Statistical Forecast

Figure 4 and Table 8 list the predictors used in the August-only hindcast (Blake 2002) for each of the nine different forecast parameters. The table also shows hindcast skill for the 51-year period 1950-2000 as well as the independent jackknife hindcast skill over this period. Table 9 also lists our independent statistical prediction for August 2002. These predictors indicate a reasonably active August 2002. The August forecast parameters for this year are a mixed bag. Five out of the seven July parameters were unfavorable for TC formation. July pressure over the subtropical Atlantic was the highest on record since 1949. However, early season predictors were strongly favorable and are possibly causing the statistical forecast to be a bit inflated this year.

Predictor Map

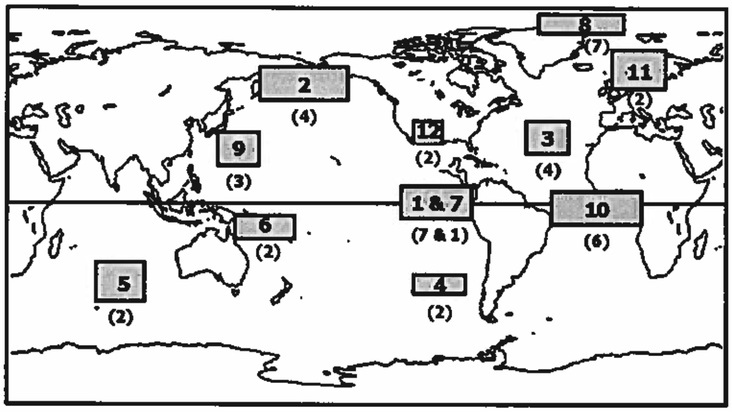

Figure 4: Global map showing locations of August-only TC predictors. Table 8 provides a listing and description of these predictors. The numbers in the boxes are keyed to descriptions in the bottom of Table 8. The numbers in parentheses beneath each box indicate how many predictor equations used each predictor.

Table 8: Listing of predictors chosen for each forecast parameter and the total hindcast variance explained by these predictors for the August-only forecast. The name and atmospheric property utilized in each predictor is given below - where the number for each is keyed to Fig. 4.

Forecast Parameter	No. of Predictors	Predictors Chosen from Table	Variability Explained by Hindcast (R^2) (1949-1999)	Likely Independent Forecast Skill (Jackknife)
NS	5	3, 6, 7, 9, 11	.55	.41
NSD	5	1, 2, 3, 8, 10	.71	.61
H	4	1, 2, 8, 10	.57	.47
HD	5	3, 4, 8, 9, 19	.69	.59
IH	5	1, 3, 5, 8, 12	.68	.59
IHD	5	1, 4, 5, 6, 9	.78	.72
NTC	5	1, 2, 8, 10, 12	.74	.66
TONS	4	1, 8, 10, 11	.68	.60
TOH	4	1, 2, 8, 10	.64	.56

1) Galapagos July 200 mb v, sign of correlation (-)
2) Bering Sea July SLP, sign of correlation (-)
3) Atlantic Ocean July SLP, sign of correlation (-)
4) SE Pacific July 200 mb u, sign of correlation (-)
5) S. Indian Ocean July 500 mb ht, sign of correlation (-)
6) Coral Sea July 200 mb u, sign of correlation (+)
7) Galapagos July 200 mb u, sign of correlation (-)
8) North Greenland June 200 mb u, sign of correlation (+)
9) Northwest Pacific June SLP, sign of correlation (+)
10) S. Atlantic Ocean April SLP, sign of correlation (-)
11) Scandinavia February SLP, sign of correlation (-)
12) SW USA January SLP, sign of correlation (-)

5.2 Independent September-Only 2002 Forecast From 1 August Forecast

Figure 5 and Table 10 portray and list our 1 August predictors for the September-only 2002 predictors. The number of predictors used and individual parameter hindcast skill are given in Table 11. Table 12 gives the sign and magnitude of each predictor for this September 2002. Table 13 gives our independent September statistical forecast and our adjusted statistical forecast.

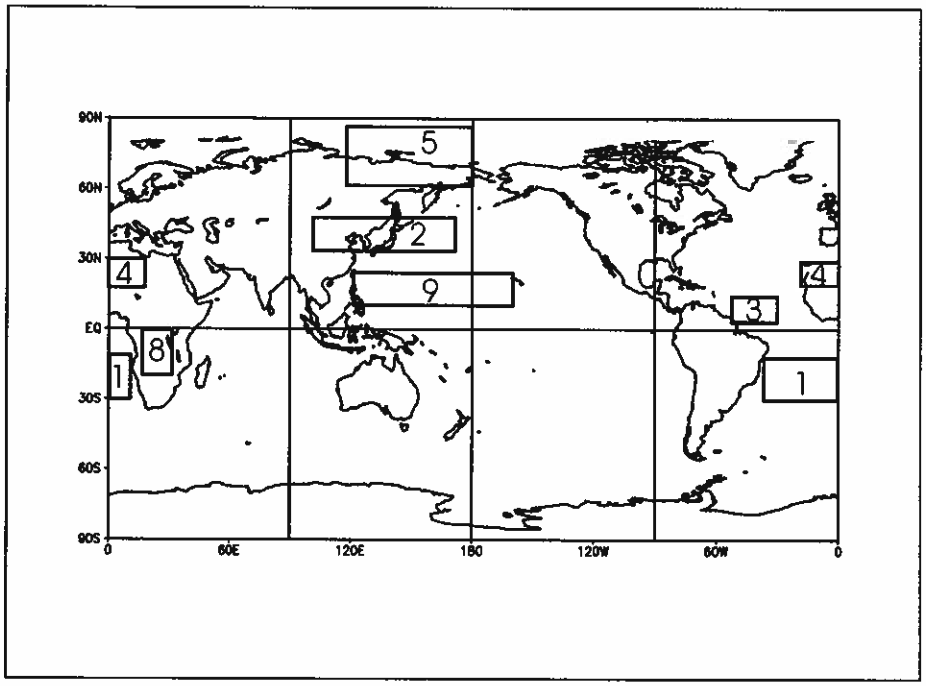

Figure 5: Predictors selected for the 1 August forecast. The numbers in each area are keyed to the description given in Table 10.

Data available through the end of July indicates that September 2002 will be less active than normal. The strongest predictor, 1000 mb U (trade winds) in the Atlantic (5-15N, 30-50W) is running about +0.8 standard deviations stronger than normal which indicates considerably less

Table 9: Independent August-only prediction of 2002 hurricane activity based on Blake (2002). August climatology is shown in parentheses.

	Statistical Model	Qualitative Adjustment
NS	2.09 (2.76)	3
NSD	18.9 (11.80)	15
H	2.6 (1.55)	2
HD	7.11 (5.67)	7
IH	0.68 (0.57)	1
IHD	1.06 (1.18)	1
NTC	31.8 (26.1)	30

Table 10: Predictors selected for the 1 August forecast of September tropical cyclone activity. The sign of the predictors associated with increased tropical cyclone activity is in parentheses. Note that predictors 6 and 7 are not used since they require August data.

Name of Predictor	Location	Equations Used
1) April 1000 mb U (-)	(12.5-30°S, 40°W-10°E)	IH
2) July 200 mb Geo Ht. (+)	(32-42°N, 100-160°E)	NS, NSD, H, HD, IH, TONS, TOH, NTC
3) July 1000 mb U (+)	(5-15°N, 30-50°W)	NS, NSD, H, HD, IH, IHD, TONS, TOH, NTC
4) Feb. 1000 mb U (-)	(20-30°N, 15°W-15°E)	NSD, HD, IHD, NTC
5) April 200 mb U (-)	(67.5-85°N, 110-180°E)	NS, NSD, HD, IH, IHD, TONS, TOH, NTC
8) May 200 mb V (+)	(0-20°S, 15-30°E)	NSD, H, HD
9) Jan-Feb 200 mb U (-)	(15-25°N, 120°E-160°W)	IH, IHD, TONS, TOH, NTC

Table 11: Variance (r^2) explained for each of the nine TC activity indices and aggregate NTC based on the 1 August hindcast of September tropical cyclone activity from 1950-2000.

Parameter	Number of Predictors	Variance Explained	Jackknife Variance Explained
NS	3	0.29	0.19
NSD	5	0.54	0.44
H	3	0.38	0.28
HD	5	0.60	0.51
IH	5	0.63	0.53
IHD	4	0.63	0.54
TONS	4	0.50	0.40
TOH	4	0.63	0.55
NTC	5	0.75	0.68
Aggregate NTC		0.80	

Table 12: September 2002 predictor values – sign is what is wanted for more storm.

1) April 1000 mb U (12.5-30S, 40W-10E) (-): +1.8 SD
2) July 200 mb Geopotential Height (32-42N,100-160E) (+): +0.6 SD
3) July 1000 mb U (5-15N,30-50W) (+): -0.7 SD
4) February 1000 mb U (20-30N, 15W-15E) (-): -0.9 SD
5) April 200 mb U (67.5-85N, 110-180E) (-): +1.5 SD
8) May 200 mb V (0-20S, 15-30E) (+): +0.6 SD
9) January-February 200 mb U (15-25N, 120E-160W) (-): -0.8 SD

Table 13: Independent 2002 September statistical forecast based on data through July 2002.

Statistical Forecast	Adjusted Statistical Forecast
NS: 2.7	NS: 3.0
H: 2.5	H: 2.0
IH: 0.8	IH: 1.0
NSD: 21.5	NSD: 21.5
HD: 12.5	HD: 12.0
IHD: 2.75	IHD: 2.5
NTC: 44.1	NTC: 42.0

storm development owing to strong shear in the main development region. The other predictors are mixed. As discussed in the following section, we likely need to lower the September statistical and adjusted forecast considering the very high sea level pressures in the Atlantic, the failed 2002 Indian monsoon, the cooling Atlantic SSTs, a warm East Pacific (El Nino), etc. An updated September-only statistical forecast will be issued on 2 September (Labor Day). This early September forecast will have the advantage of August data.

6 Required Downward Adjustment to August and September Individual Monthly Forecasts

The current season is special in view of the unusual and rapid increase in inhibiting atmospheric and oceanic conditions during the spring and early summer. We believe that the current strongly inhibiting values of Atlantic basin SLPA, SSTA, and upper and lower tropospheric zonal winds will 'trump' any of the pre-June monthly predictors in our seasonal and individual August and September forecasts and in most of our analog years. Given the current (July) inhibiting conditions in the Atlantic basin we have decided to somewhat reduce both individual monthly predictions. We see the current Atlantic basin conditions as taking precedence over most of our other individual predictors and analog years in Table 14. Hence, as listed in Table 15, downward adjustments of both of these August and September monthly forecast values appears prudent.

Table 14: August and September predictions and the new downward adjustments in view of July 2002 Atlantic basin conditions. The monthly climatology is given in parentheses.

	Adjusted Model Prediction	August Adjustment to	September Model Prediction	September Adjustment to
NS	2.09 (2.76)	4	2.7 (3.4)	3
NSD	18.9 (11.80)	10	21.5 (21.7)	18
H	2.6 (1.55)	1	2.5 (2.4)	2
HD	7.11 (5.67)	4	12.5 (12.3)	6
IH	0.68 (0.57)	0	0.8 (1.3)	1
IHD	1.06 (1.18)	0	2.75 (3.0)	2
NTC	31.8 (26.1)	18	44.1 (48)	30

7 Landfall Probabilities for 2002

A significant focus of our recent research involves efforts to develop forecasts of the probability of hurricane landfall along the U.S. coastline. Whereas individual hurricane landfall events can never be accurately forecast months in advance, the seasonal probability of landfall can be forecast with statistical skill. The mean frequency of hurricane landfall over extended periods, say 5 years or longer, is directly related to the mean frequency of Atlantic basin hurricanes. With the observation that Atlantic basin and US landfall probability varies as a function of seasonal and monthly global circulation conditions, a probability specification scheme has been developed through statistical

Table 15: Adjusted estimates of Atlantic basin tropical cyclone activity predicted for the two 2002 individual monthly forecasts.

	Pre-1 Aug	Post 1 Aug Fcst			Full
	Observed	Aug	Sept	Oct-Nov	Season
NS	1	4	3	1	9
NSD	1	10	18	6	35
H	0	1	2	1	4
HD	0	4	6	2	12
IH	0	0	1	0	1
IHD	0	0	2	0	2
HDP	0	10	20	5	35
NTC	1	18	30	12	60

analyses of all U.S. hurricane and named storm landfall events during the 100 year period of the 20th century (1900–1999). Specific seasonal landfall probabilities can be assessed for all cyclone intensity classes for a set of distinct U.S. coastal regions.

Net landfall probability is most closely linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see explanation in caption of Table 16) and to climate trends associated with the multi-decadal variations of the Atlantic Ocean thermohaline circulation. The latter is expressed in terms of SSTA*, an index of North Atlantic SSTA in the area between 50-60°N, 10-50°W. SSTA* is a combination average of North Atlantic SSTA during the last six years.

Warm SSTA* values generally indicate greater Atlantic hurricane activity, especially for major hurricanes. Hence, Atlantic basin NTC can be skillfully predicted and the recent strength of the Atlantic Ocean thermohaline circulation can be inferred from positive SSTA values in the North Atlantic. These relationships are then utilized to make estimates of landfall probability for the U.S. coast. The current 2002 value for SSTA* is 91. Following the prior discussion in Section 6 it is likely that this very high value of SSTA*, which has been constructed from data averaged for the past six years of very warm North SST, will be way too high and unrepresentative of June-July 2002 conditions. The unusual 2002 global atmospheric and oceanic changes have largely occurred since the spring period. In light of this year's unexpected high values of Arctic Oscillation (AO) and North Atlantic Oscillation (NAO) and the surprising cooling of the Atlantic SSTs in recent months, we have decided to reduce the very high SSTA* value of 91 to a value of only one-third this amount, or 30. This adjustment leads to a new value of NTC + SSTA* as follows. We forecast NTC for 2002 to be 60. Applying the previously designated value of SSTA* of 30, we arrived at the combination of NTC + SSTA* of 60 + 30 = 90 which is much reduced from our earlier seasonal forecasts. This adjustment also means that we expect U.S. landfall probability to be about 80/50 or 1.6 times higher than the overall Atlantic basin activity.

As shown in Table 16, NTC is a combined measure of the year-to-year mean of six indices of hurricane activity, expressed as a percentage deviation from its long-term averages. Although many active Atlantic seasons have no landfalling hurricanes and some inactive years have one or more landfalling hurricanes, long-term statistics show that, on average, the more active the overall Atlantic basin hurricane season, the greater the probability of U.S. hurricane landfall. For example, landfall observations during the 20th century show that a greater number of intense (Saffir-Simpson category 3-4-5) hurricanes strike the Florida and U.S. East Coast during years of (1) highest NTC and, (2) above-average North Atlantic SSTA*. The 33 years with the combined highest NTC + SSTA* during the 20th century had 24 category 3-4-5 hurricane strikes along the Florida and East Coast whereas, the 33 years with the lowest NTC + SSTA* saw only three such intense hurricane landfall events, resulting in a difference of 8 to 1.

Table 16: NTC activity in any year consists of the seasonal total of the following six parameters expressed in terms of their long-term averages. A season with 10 NS, 50 NSD, 6 H, 25 HD, 3 IH, and 5 IHD, would then be the sum of the following ratios: 10/9.6 = 104, 50/49.1 = 102, 6/5.9 = 102, 25/24.5 = 102, 3/2.3 = 130, 5/5 = 100, divided by six, yielding an NTC of 107.

	1950-2000 Average	
1)	Named Storms (NS)	9.6
2)	Named Storm Days (NSD)	49.1
3)	Hurricanes (H)	5.9
4)	Hurricane Days (HD)	24.5
5)	Intense Hurricanes (IH)	2.3
6)	Intense Hurricane Days (IHD)	5.0

Tables 17 and 18 summarize the links between hurricane and tropical storm landfall and the combined influences of NTC and the thermohaline circulation (i.e., North Atlantic SSTA* effects) for Florida, the U.S. East Coast and for the Gulf Coast (NTC only). Landfall characteristics for the Gulf Coast (Fig. 6) (or regions 1-4) from north of Tampa, FL westward to Brownsville, TX have related landfall probabilities which are distinct from the rest of the U.S. coast from north of Tampa, FL to Eastport, ME (Regions 5-11). These differences are due primarily to the varying incidence of category 3-4-5 hurricanes in each of these areas.

Table 17: Number of Florida Peninsula and U.S. East Coast (regions 5 through 11) hurricane landfall events by intensity class occurring for the 33 highest versus the 33 lowest values of NTC plus Atlantic thermohaline circulation (SSTA*) or NTC + SSTA* during the last century.

Intensity Category	Sum of Highest 33 Years	Sum of Lowest 33 Years	Ratio of Highest/Lowest 33 Years
IH (Category 3-4-5)	24	3	8.0
H (Category 1-2)	29	12	2.4
NS	24	17	1.4

Figure 7 gives a flow diagram outlining the procedures by which these landfall forecasts are made. Using NTC alone, a similar set of regression relationships has been developed for the landfall probability of category 1-2 hurricanes and tropical storms along the Gulf Coast (regions 1-4) and along the Florida Peninsula and East Coast (regions 5-11). Table 19 lists strike probabilities for each TC category for the entire U.S. coastline, the Gulf Coast and Florida, and the East Coast for 2002. The mean annual probability of one or more landfalling systems is shown in parentheses.

Table 18: Number of Gulf (regions 1 through 4) hurricane landfall events by intensity class during the seasons with the 33 highest and 33 lowest NTC values during this century.

Intensity Category	Sum of Highest 33 Years	Sum of Lowest 33 Years	Ratio of Highest/Lowest 33 Years
IH (Category 3-4-5)	18	5	3.6
H (Category 1-2)	22	11	2.0
NS	28	27	1.0

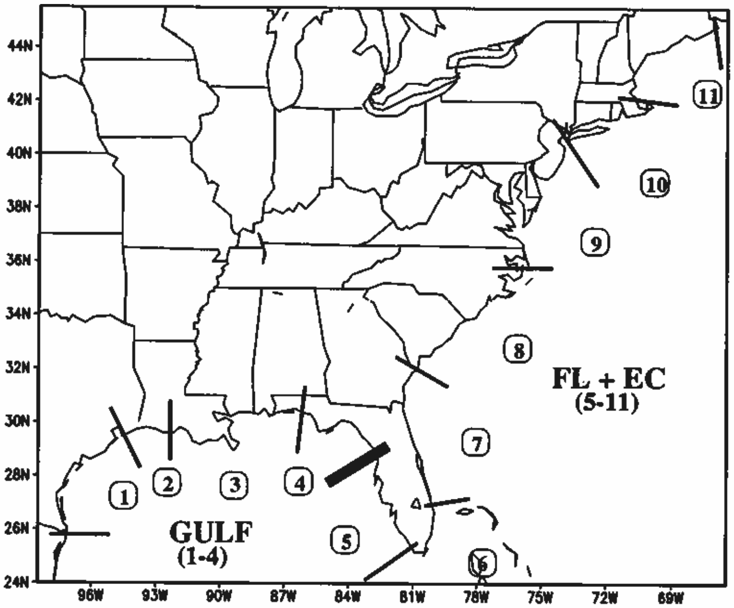

Figure 6: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made. The heavy bar delineates the boundary between the Gulf (regions 1-4) and the Florida Peninsula and East Coast (regions 5-11).

Note that Atlantic basin forecast NTC activity for 2002 is 60 percent of the long-term average. U.S. hurricane landfall probability is expected to be above average owing to North Atlantic SSTAs being above average in recent years. During periods of positive North Atlantic SSTA*, a significantly higher percentage of Atlantic basin major hurricanes cross the Peninsula Florida and the U.S. East Coast.

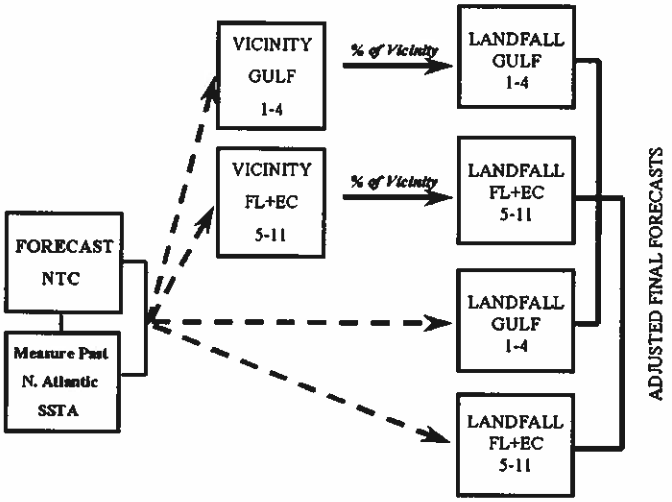

Figure 7: Flow diagram illustrating how forecasts of U.S. hurricane landfall probabilities are made. Forecast NTC values and an observed measure of recent North Atlantic (50-60°N, 10-50°W) SSTA* are used to develop regression equations from U.S. hurricane landfall measurements of the last 100 years. Separate equations are derived for the Gulf and for Florida and the East Coast (FL+EC).

Table 19: Estimated probability for 2002 (expressed in percent) of one or more U.S. landfalling tropical storms (TS), category 1-2 hurricanes, category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (region 1-4), and along the Florida and the East Coast (Regions 5-11)2. The long-term mean annual probability of one or more landfalling systems during the last 100 years is given in parentheses.

Coastal Region	TS	Category 1-2 HUR	Category 3-4-5 HUR	All HUR	All Named Storms
Entire U.S. (Regions 1-11)	78% (80)	66% (68)	49% (52)	82% (84)	96% (97)
Gulf Coast (Regions 1-4)	57% (59)	41% (42)	29% (30)	58% (61)	82% (83)
Florida plus East Coast (5-11)	49% (51)	42% (45)	28% (31)	58% (62)	79% (81)

8 The 2002 Hurricane Season and the Increased Level of Atlantic Basin Hurricane Activity During the Last Seven Years

The last seven seasons (1995-2001) have been the most active seven consecutive years of Atlantic basin hurricane activity on record. There have been a total of 94 named storms, 524 named storm days, 58 hurricanes, 266 hurricane days, 27 intense hurricanes and 61 intense hurricane days.

As has been extensively discussed in recent years, we believe that since 1995, a new 20-30 year era of increased Atlantic basin hurricane activity has been in place, particularly for intense (category 3-4-5) hurricane activity. This multi-decadal Atlantic basin increase follows a large downturn in major hurricane activity during the 25 years between 1970-1994. We attribute these multi-decadal trends to concurrent variations of the Atlantic Ocean thermohaline circulation.

The anticipated dip in hurricane activity for 2002 does not signal the end of the current multi-decadal era of enhanced major hurricane activity. Within each active or inactive multi-decadal era, individual years will depart from the longer period trend. For example, the years of 1988 and 1989 were quite active and not indicative of the overall suppressed conditions of the Atlantic basin activity between 1970 and 1994. Similarly, the suppressed hurricane years of 1946, 1962 and 1968 were exceptional during the overall active period of the 1930s through the 1960s. Thus, we see the large downturn in expected hurricane activity for 2002 as not unusual but typical of the year-to-year variability that occurs within both enhanced and suppressed multi-decadal periods.

If the future is like the past, it is highly likely that very active hurricane seasons such as those between 1995-2001 will again emerge during the next few years and the prospects for very large US and Caribbean increases in hurricane damage over the next few decades remain high. We should indeed see future hurricane damage much greater than anything in the past as future storms begin to impact the very greatly increased coastal population and property values.

9 The 1995-2001 Upswing in Atlantic Hurricanes and Global Warming

It has been variously suggested that the recent large upswing in Atlantic hurricane activity (since 1995) may be in some way related to the effects of increased anthropogenic greenhouse gases such as carbon dioxide (CO_2). There is no reasonable scientific basis for such an interpretation. This recent upward shift in Atlantic basin hurricane activity is natural and not a result of anthropogenic greenhouse gas release. Please see our recent 20 November 2001 verification report (http://tropical.atmos.colostate.edu/forecasts/index.html) for more discussion on this subject.

10 Forecast Theory and Cautionary Note

Our forecasts are based on the premise that those global oceanic and atmospheric conditions which preceded comparatively active or inactive hurricane seasons in the past provide meaningful information about likely similar trends in future seasons. It is important that the reader appreciate that these seasonal forecasts are based on statistical schemes which, owing to their intrinsically probabilistic nature, will fail in some years. Moreover, these forecasts do not specifically predict where within the Atlantic basin these storms will strike. Landfall probability for any one location along the coast is very low and reflect the fact that, even during the most active seasons, most U.S. coastal areas are unlikely to feel the effects of a hurricane. Conversely, it must also be emphasized that a low landfall probability does not insure that a hurricane will not come ashore at any specific location. For example, though the season of 1992 was very inactive, Hurricane Andrew (the only major hurricane that year) caused extensive damage in South Florida and Louisiana. Similarly, regardless of how active the 2002 hurricane season is, a finite probability always exists that one or more hurricanes may strike along the U.S. or Caribbean Basin coastline and do much damage.

11 Forecast Verification

Our four forecasts of 2002 will be verified and critiqued in late November 2002. Our first seasonal forecast for the 2003 season will be issued by early December 2002. All forecast verifications and new forecasts will be made available at our web address (also given on the front cover).

(http://tropical.atmos.colostate.edu/forecasts/index.html)

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APPENDIX A

Table 1: Summary verifications of the authors prior three seasonal forecasts of Atlantic TC activity (1999-2001).

1999	5 Dec 1998	Update 7 April	Update 4 June	Update 6 August	Obs.
No. of Hurricanes	9	9	9	9	8
No. of Named Storms	14	14	14	14	12
No. of Hurricane Days	40	40	40	40	43
No. of Named Storm Days	65	65	75	75	77
Hurr. Destruction Potential(HDP)	130	130	130	130	140
Major Hurricanes (Cat. 3-4-5)	4	4	4	4	5
Major Hurr. Days	10	10	10	10	15
Net Trop. Cyclone Activity	160	160	160	160	193

2000	8 Dec 1999	Update 7 April	Update 7 June	Update 4 August	Obs.
No. of Hurricanes	7	7	8	7	8
No. of Named Storms	11	11	12	11	14
No. of Hurricane Days	25	25	35	30	32
No. of Named Storm Days	55	55	65	55	66
Hurr. Destruction Potential(HDP)	85	85	100	90	85
Major Hurricanes (Cat. 3-4-5)	3	3	4	3	3
Major Hurr. Days	6	6	8	6	5.25
Net Trop. Cyclone Activity	125	125	160	130	134

2001	7 Dec 2000	Update 6 April	Update 7 June	Update 7 August	Obs.
No. of Hurricanes	5	6	7	7	9
No. of Named Storms	9	10	12	12	15
No. of Hurricane Days	20	25	30	30	27
No. of Named Storm Days	45	50	60	60	62
Hurr. Destruction Potential(HDP)	65	65	75	75	71
Major Hurricanes (Cat. 3-4-5)	2	2	3	3	4
Major Hurr. Days	4	4	5	5	5
Net Trop. Cyclone Activity	90	100	120	120	142

Table 2: Alteration of Atlantic basin tropical cyclone climatology when the base period is changed from 1950-1990 to 1950-2000.

	1950–1990	1950–2000	Difference
No. of Hurricanes	5.8	5.9	0.1
No. of Named Storms	9.3	9.6	0.3
No. of Hurricane Days	23.7	24.5	0.8
No. of Named Storm Days	46.9	49.1	2.2
Hurr. Destruction Potential(HDP)	71.7	72.7	11.0
Major Hurricanes (Cat. 3-4-5)	2.2	2.3	0.1
Major Hurr. Days	4.7	5.0	0.3
Net Trop. Cyclone Activity	100	100	0